Physics Topic Implications on Reconstruction

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Introduction

- Neutrino physics (oscillations and cross sections) and proton decay
- Physics requirements for LArTPC:

✓ Big volume.

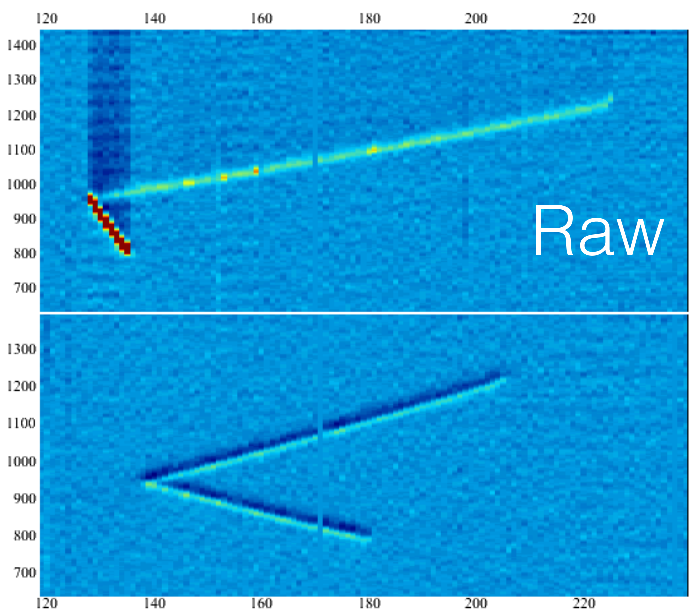
✓ High resolution.

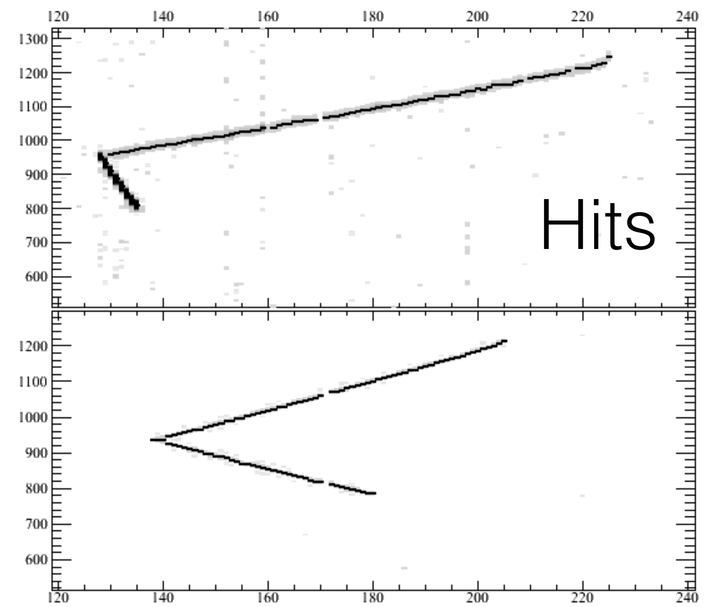
- Particle identification (e/π^0 separation, Kaon identification, $\pi^{\pm}/p$ separation).
- Energy/momentum measurements (range, multiple scattering, calorimetry).
- Collaborative effort on reconstruction needed.

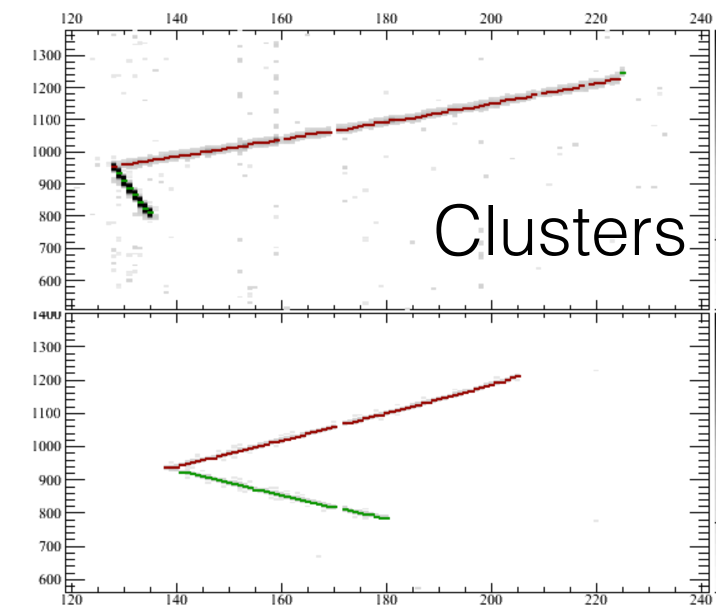
Main Questions in Neutrino Physics

- Most of them can be answered by measuring $\nu_\mu \rightarrow \nu_e$ transitions.
  - Short baseline: search for **sterile neutrinos**
  - Long baseline: matter effects resolve **mass hierarchy**, neutrinos vs antineutrinos: measure **CP violation**
- Detector requirements
  - Massive: large statistics
  - Good granularity: e/π^0 separation
- Liquid argon TPC (LArTPC) can achieve both large mass and good granularity

Conventional 3D Reconstruction



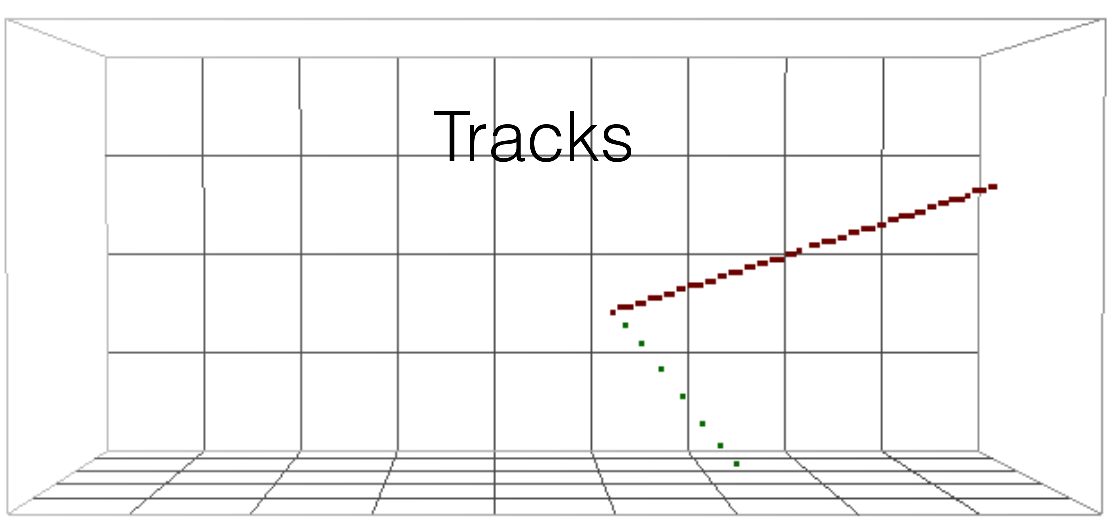




Deconvolution
Hit Finder

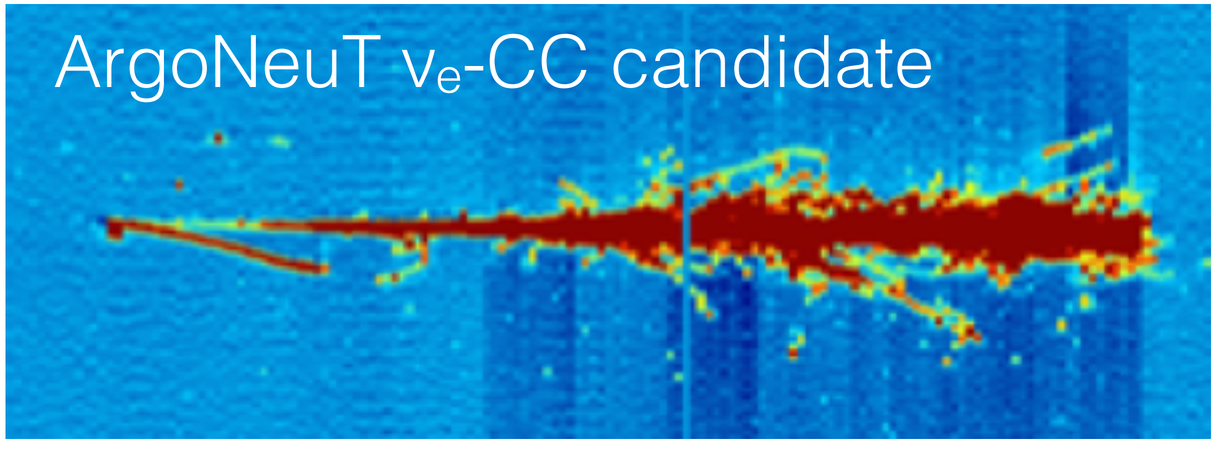
Cluster Reconstruction

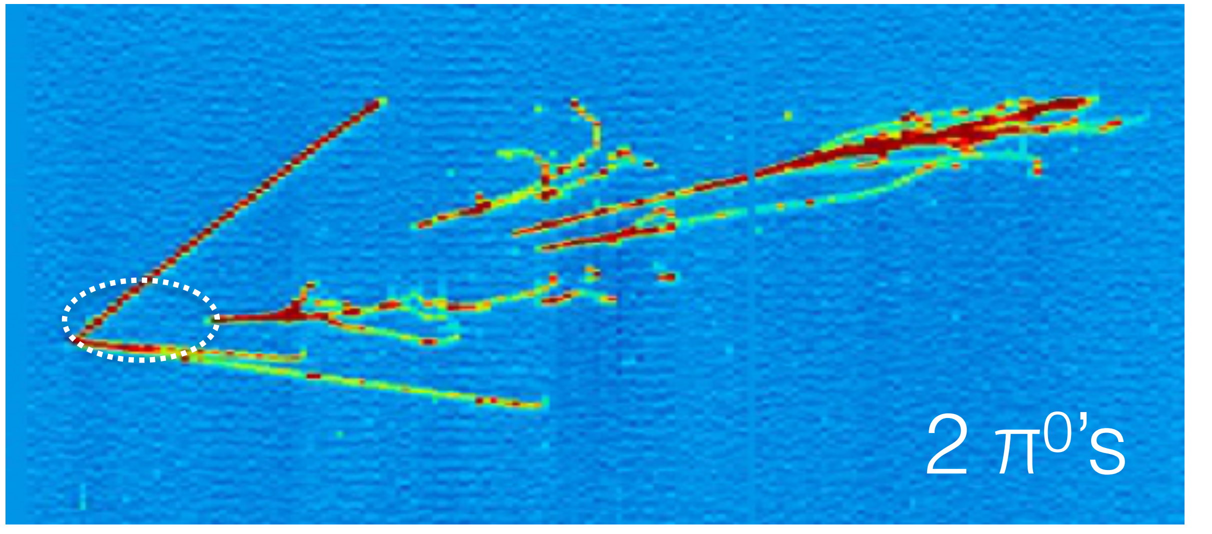
Track Reconstruction



Traditional method:
2D->3D using time matching

e/π^0 Separation

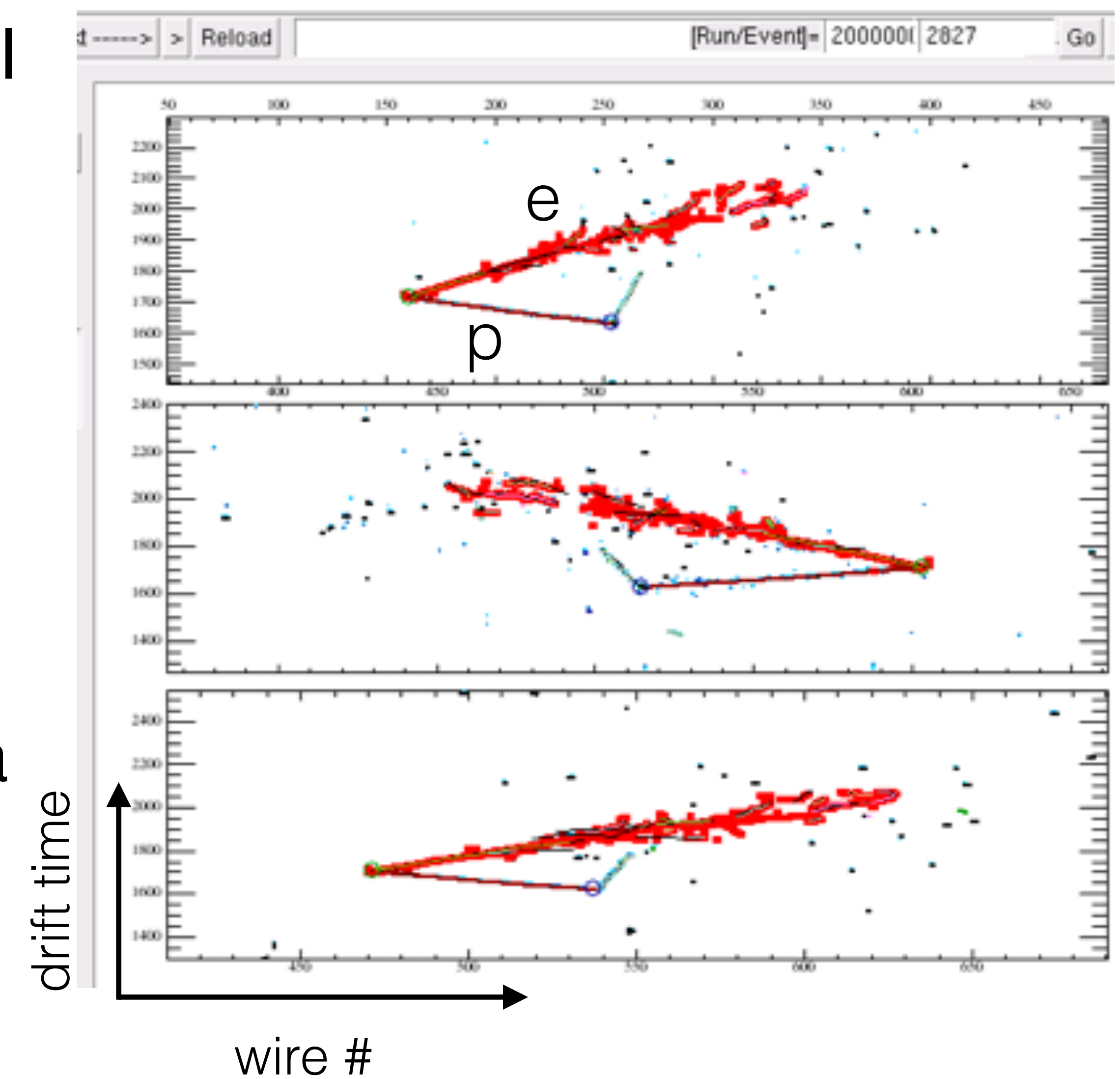




- e/π^0 separation can be achieved using topological and energy information.
  - There is usually a gap between the photon conversion point and the neutrino interaction vertex.
  - Electron and photon have different energy deposition profiles.

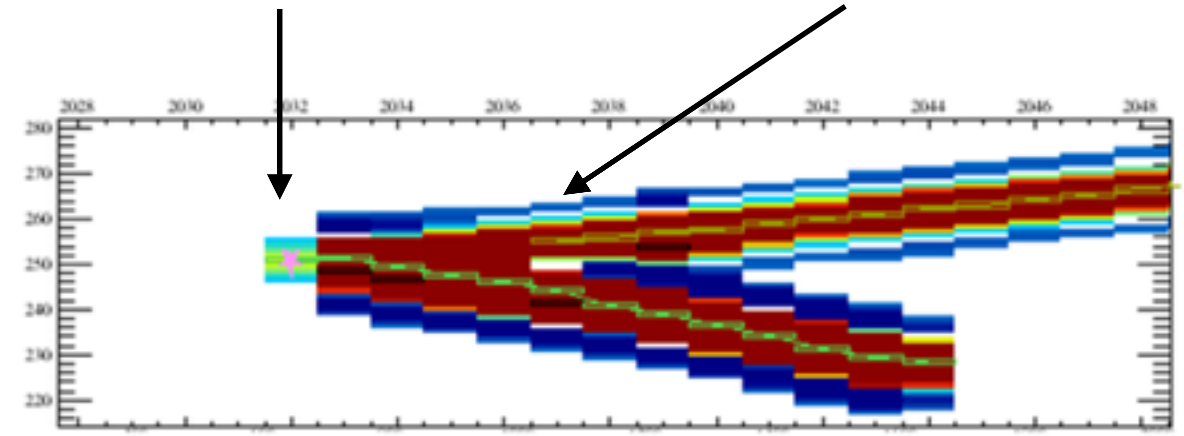
Challenges in e/π^0 Separation

- The electron shower in a neutrino interaction is often accompanied by several hadron tracks.
  - We need to separate the shower from the tracks.
  - This requires well reconstructed neutrino vertex.
- Two useful discriminating variables (Dorota Stefan)
  - Distance between shower start point and neutrino vertex in 3D.
  - Gap between shower start point and neutrino vertex in 2D view.



Track/Shower Overlaps

- Track and shower can overlap in the 2D view, especially near the interaction vertex.
- For the e signal events, sometimes there is a gap between the start start point and neutrino vertex.
- For the photon background, the photon shower can overlap with a track, making the gap invisible.



There is an artificial gap between two track start points.

Shower is overlapping with track: No gap!

WireCell is the Rescue

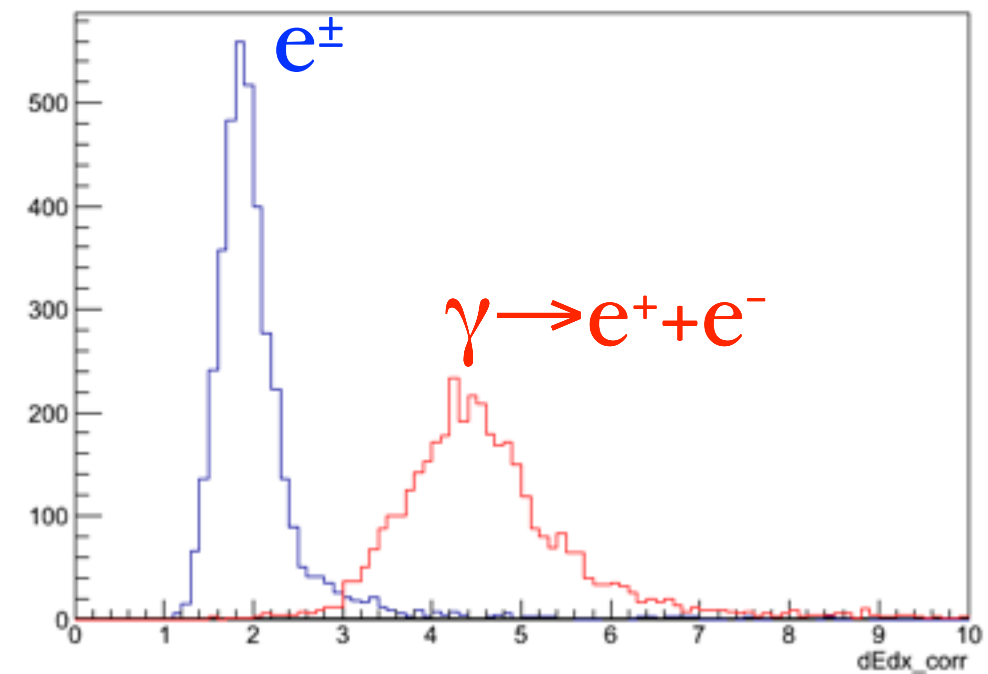
- Many of those difficulties are hard to bypass if one sticks to the traditional approach: pattern recognition in 2D first and then match different views to build 3D objects.

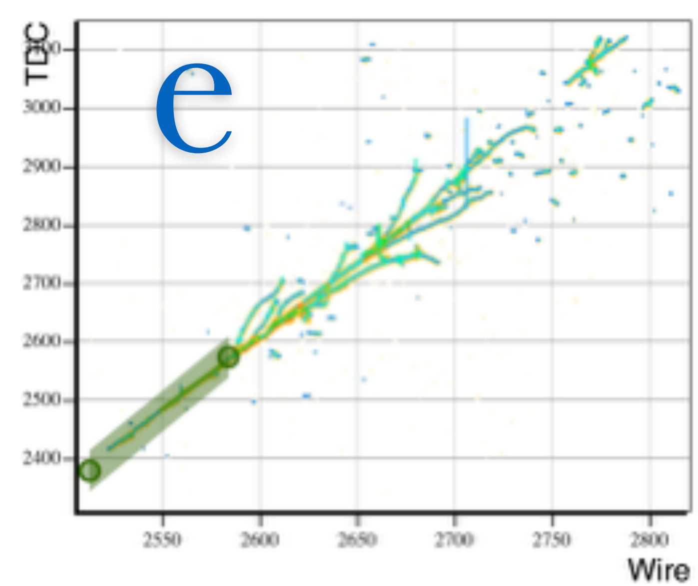
- By reconstructing the 3D image first using the WireCell approach, one can resolve a lot of ambiguities around the neutrino vertex. Tracks and showers are well separated and it is easy to spot gaps.

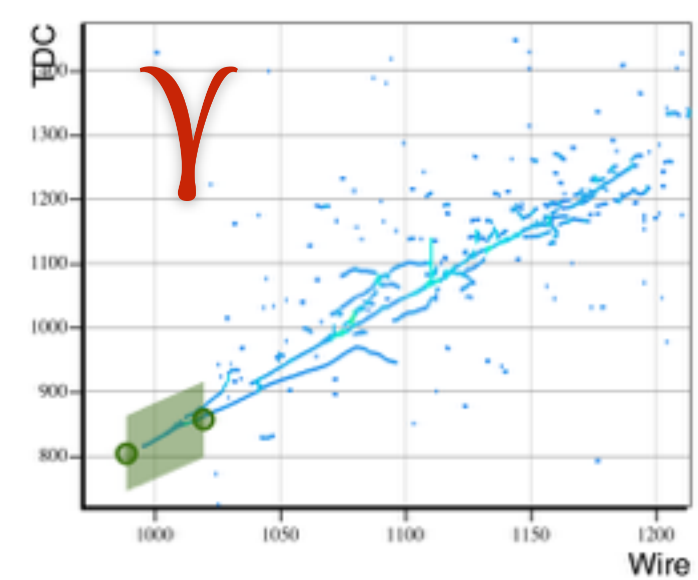
dE/dx information

- dE/dx of the initial cascade is useful in separating photons from electrons.

- Calorimetry reconstruction:
  - Direction of the shower.
  - Electronics and field response.
  - Lifetime and diffusion corrections.
  - Recombination correction.
  - Nonuniform electric field.







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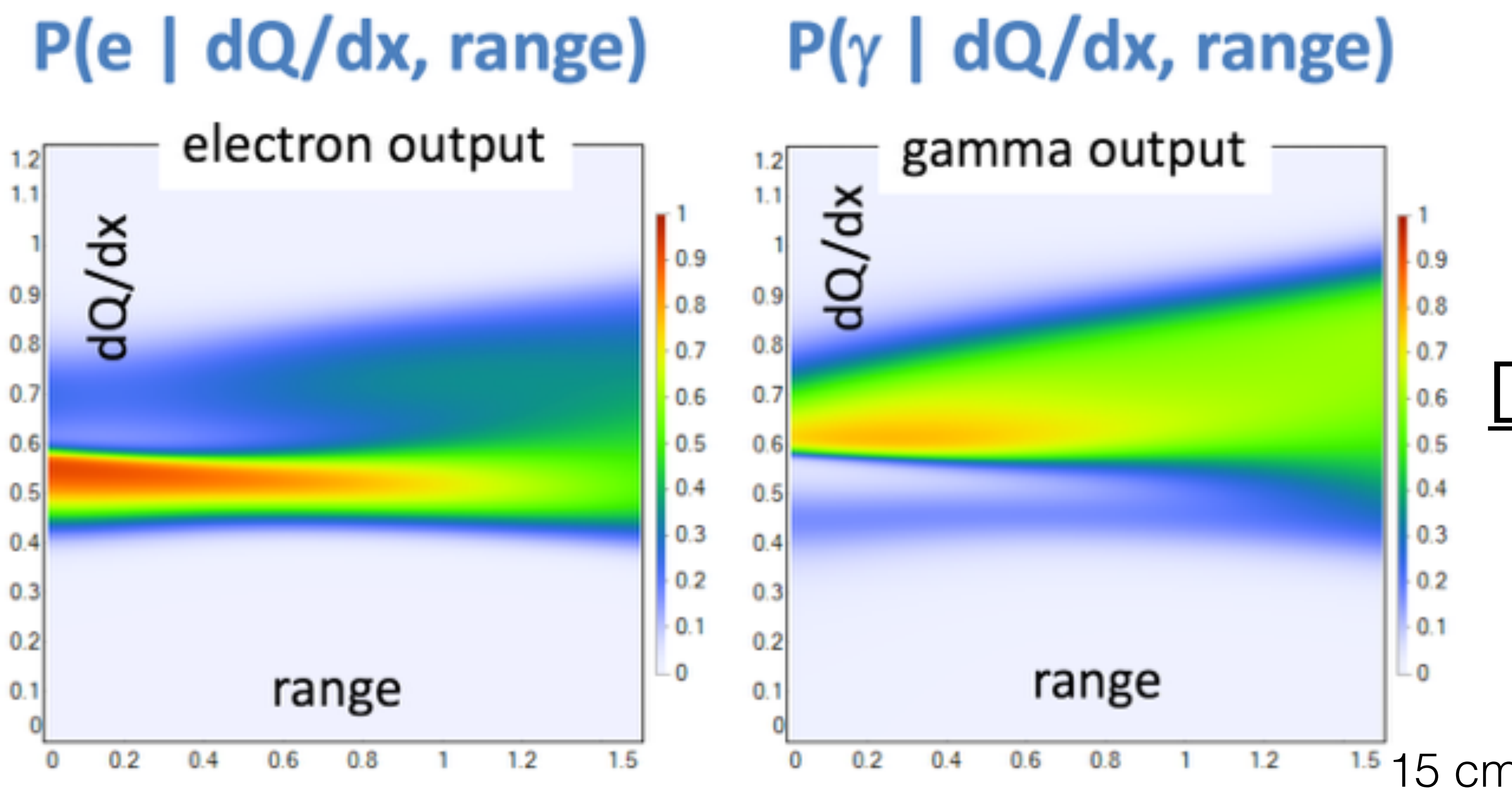
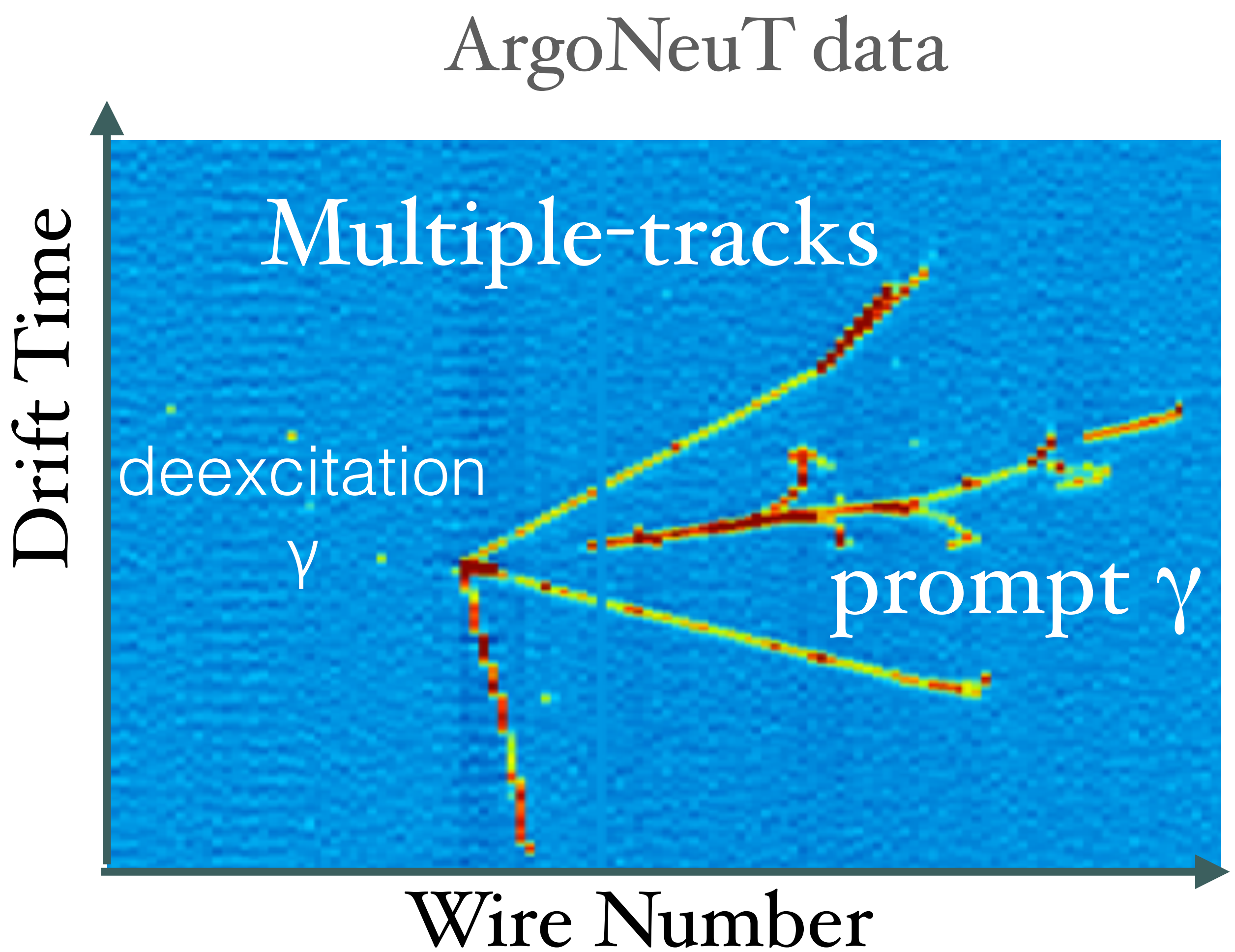
Use the Full Shower Information

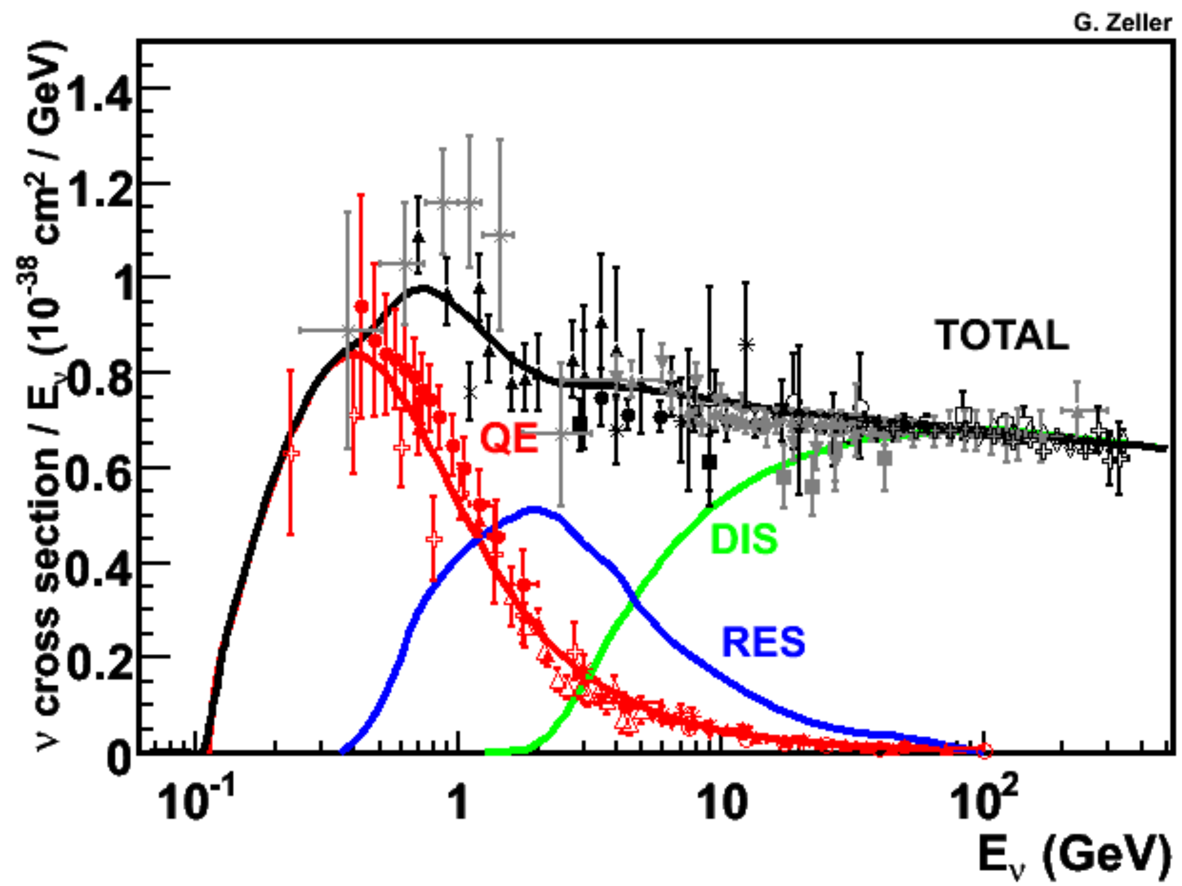


Dorota Stefan's talk

- Traditionally people calculates dE/dx using the first 2.5 cm of the initial shower segment.
- There is more information if one use the full shower profile.

Neutrino Cross Section Measurements



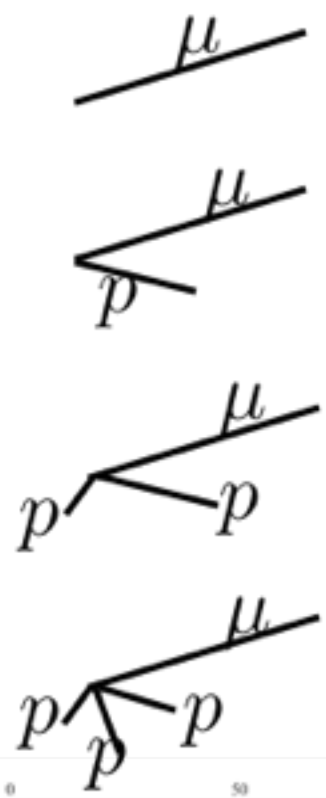


- LArTPC provides detailed information on neutrino- Ar interactions.
- Very useful information on nuclear effects.

Requirements for Cross Section Measurements

- Identify particles (both charged and neutral) originated from the neutrino interaction.
- Reconstruct individual tracks and showers.
  - WireCell reconstruction should have much higher efficiency compared with 2D based reconstruction.
- Calorimetry reconstruction and particle identification using dE/dx information and topology.

ArgoNeuT’s 0-pi Analysis

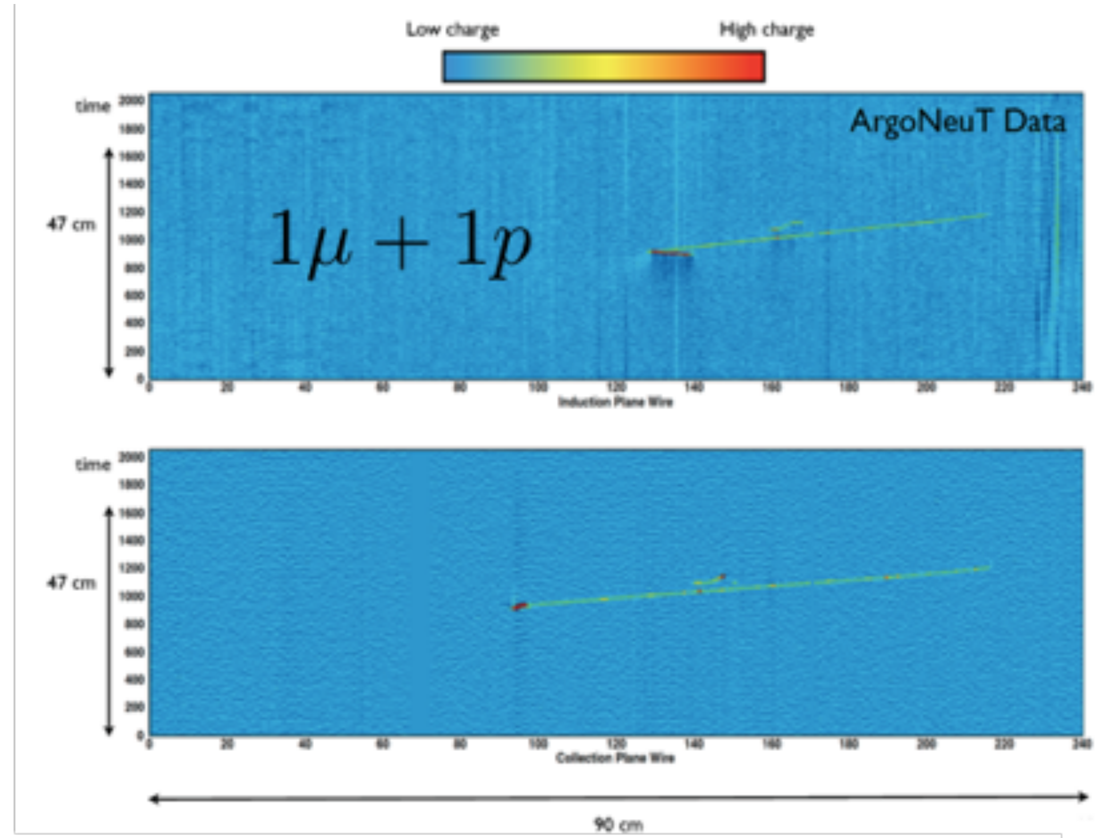


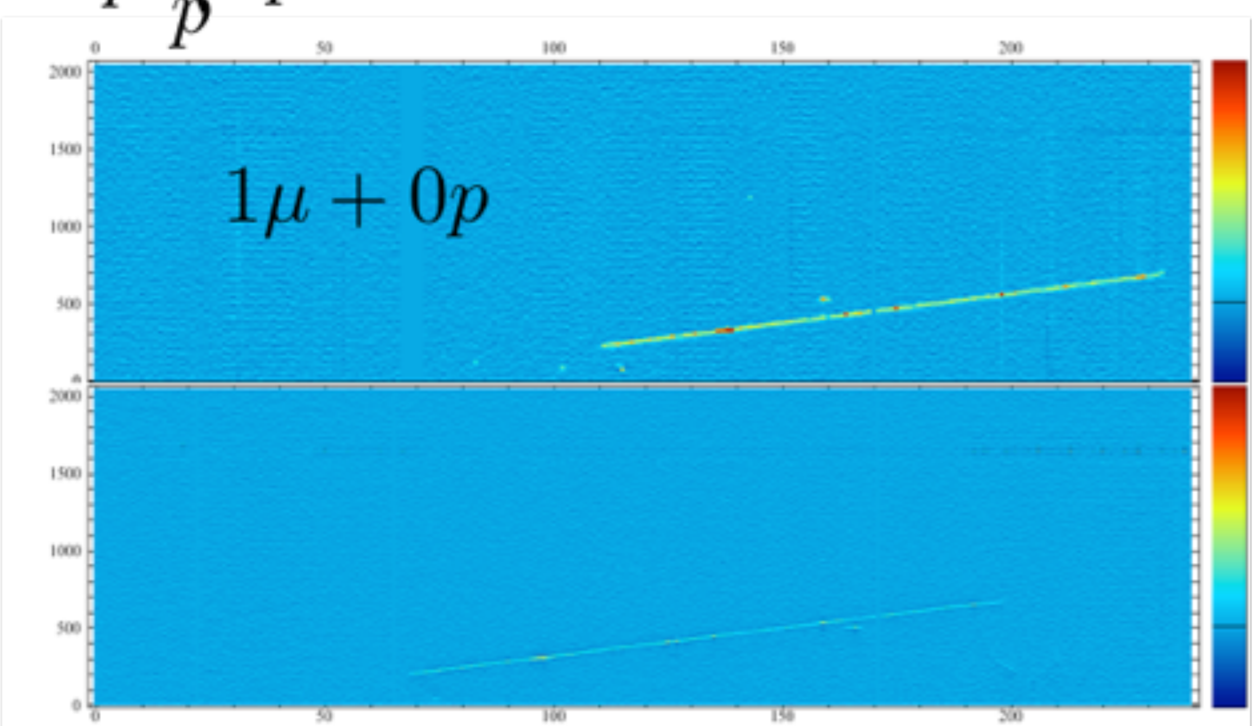
$1\mu + 0p$

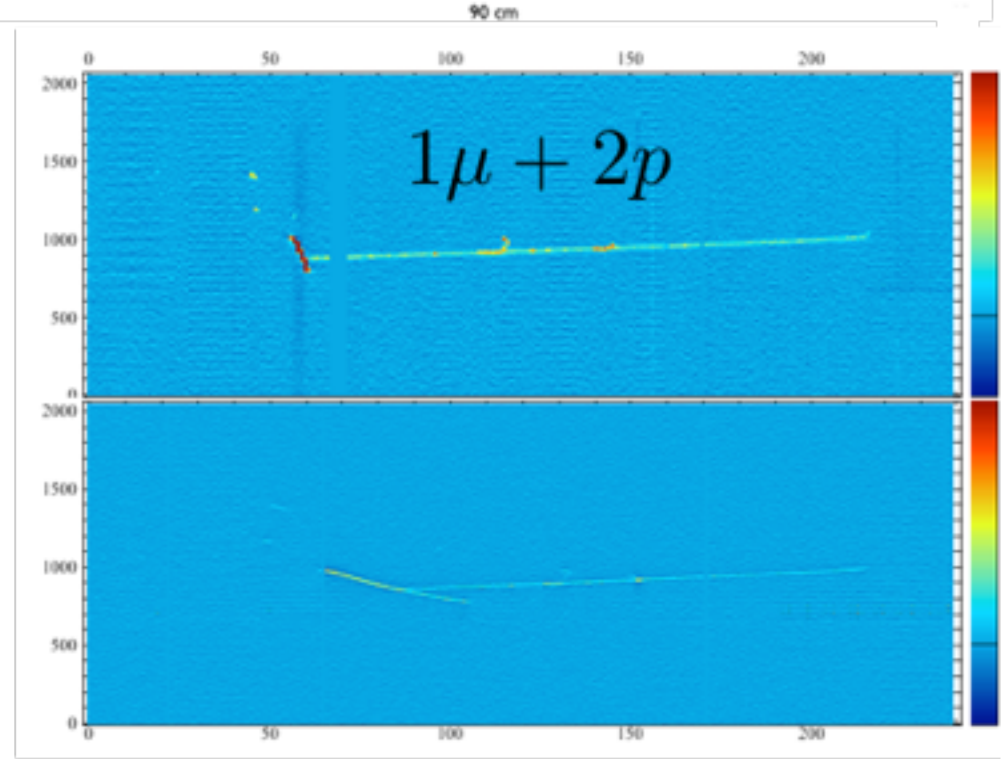
$1\mu + 1p$

$1\mu + 2p$

$1\mu + 3p$

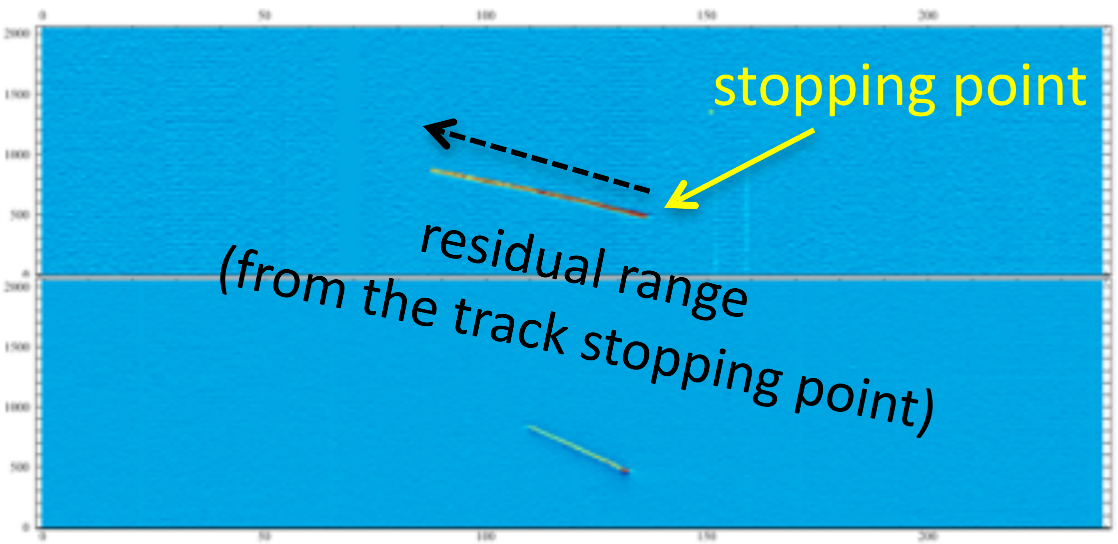






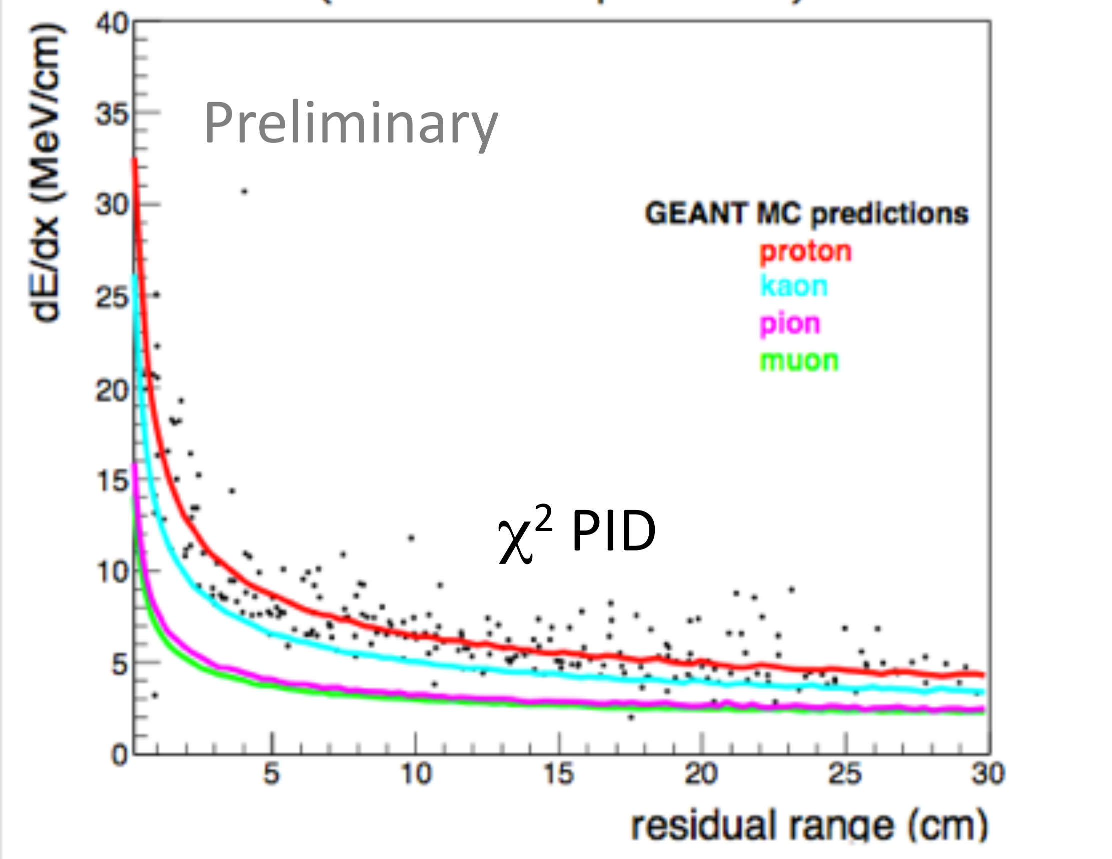
Semi-automated reconstruction.

Calorimetric ParticleID

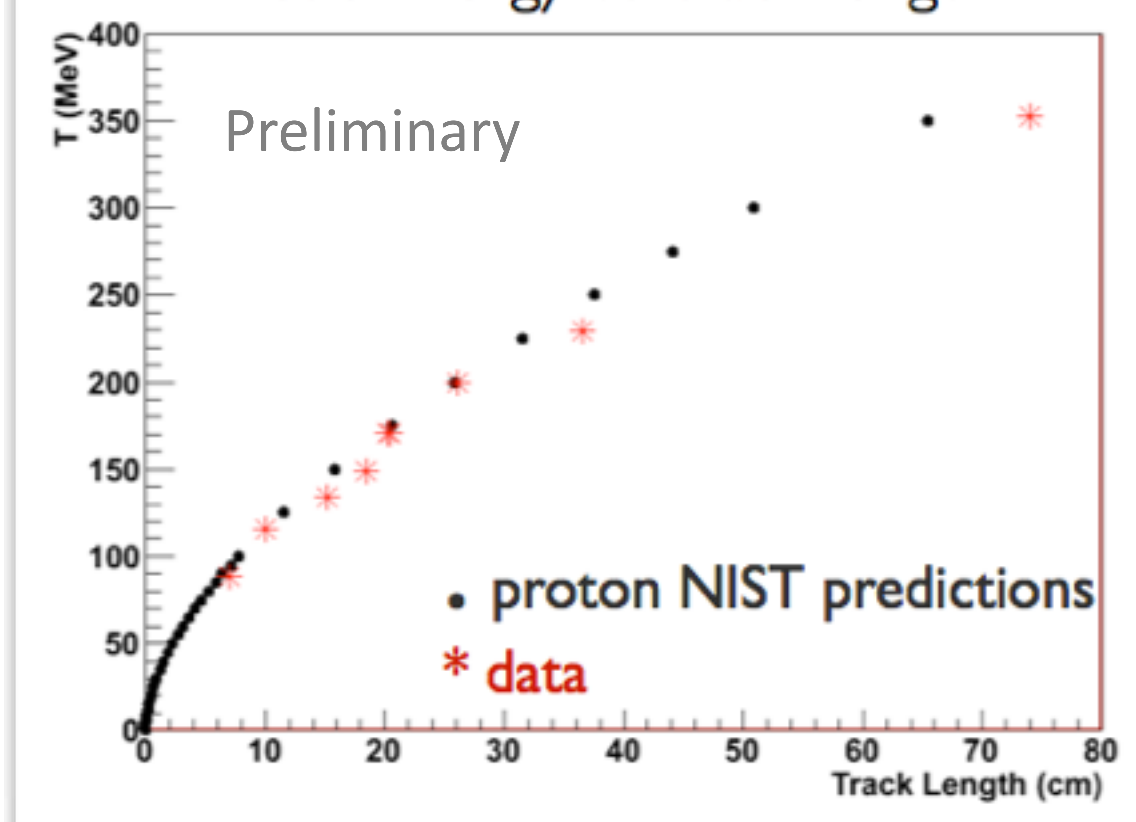


- Measurement of:
  - dE/dx vs. residual range along the track
  - kinetic energy vs. track length

dE/dx vs. residual range (contained protons)

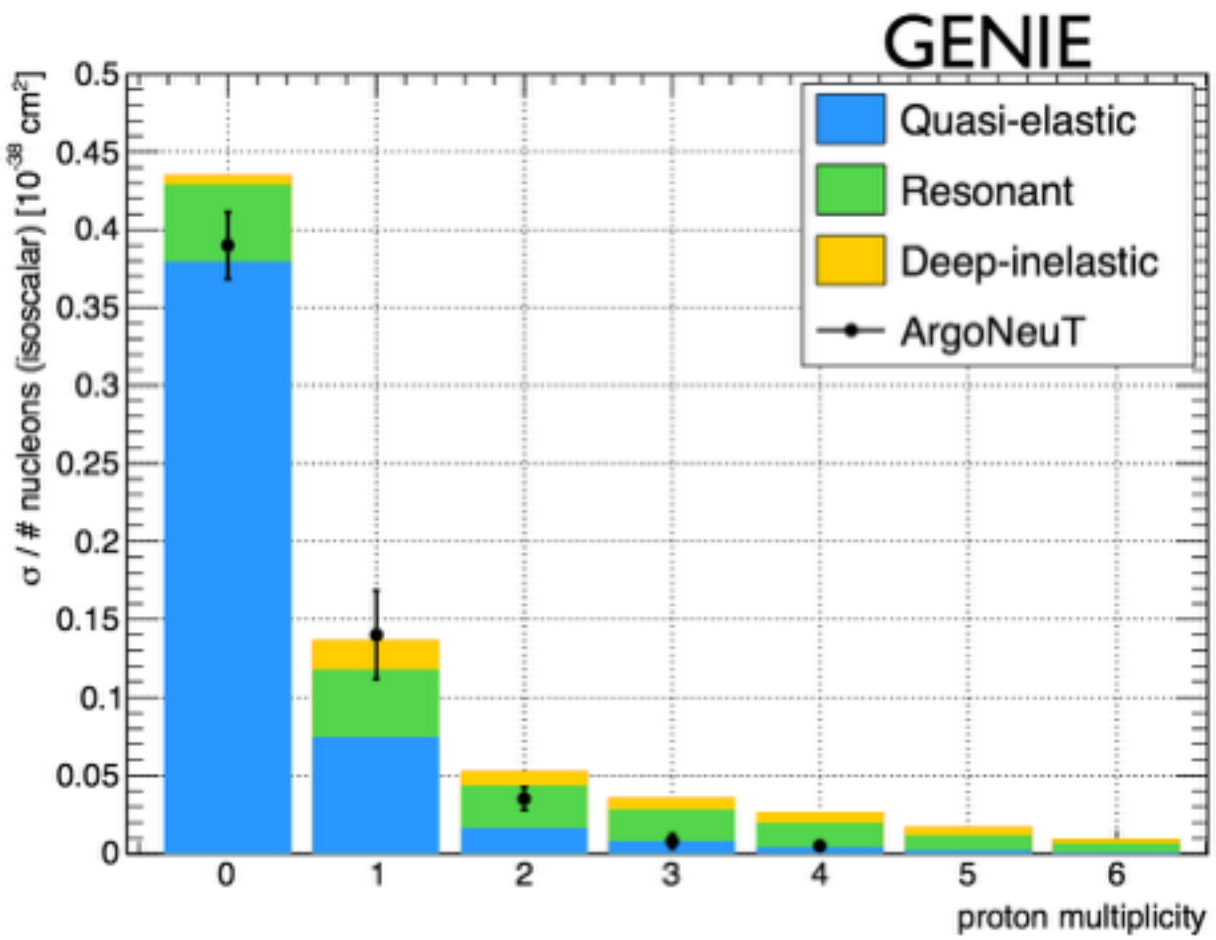


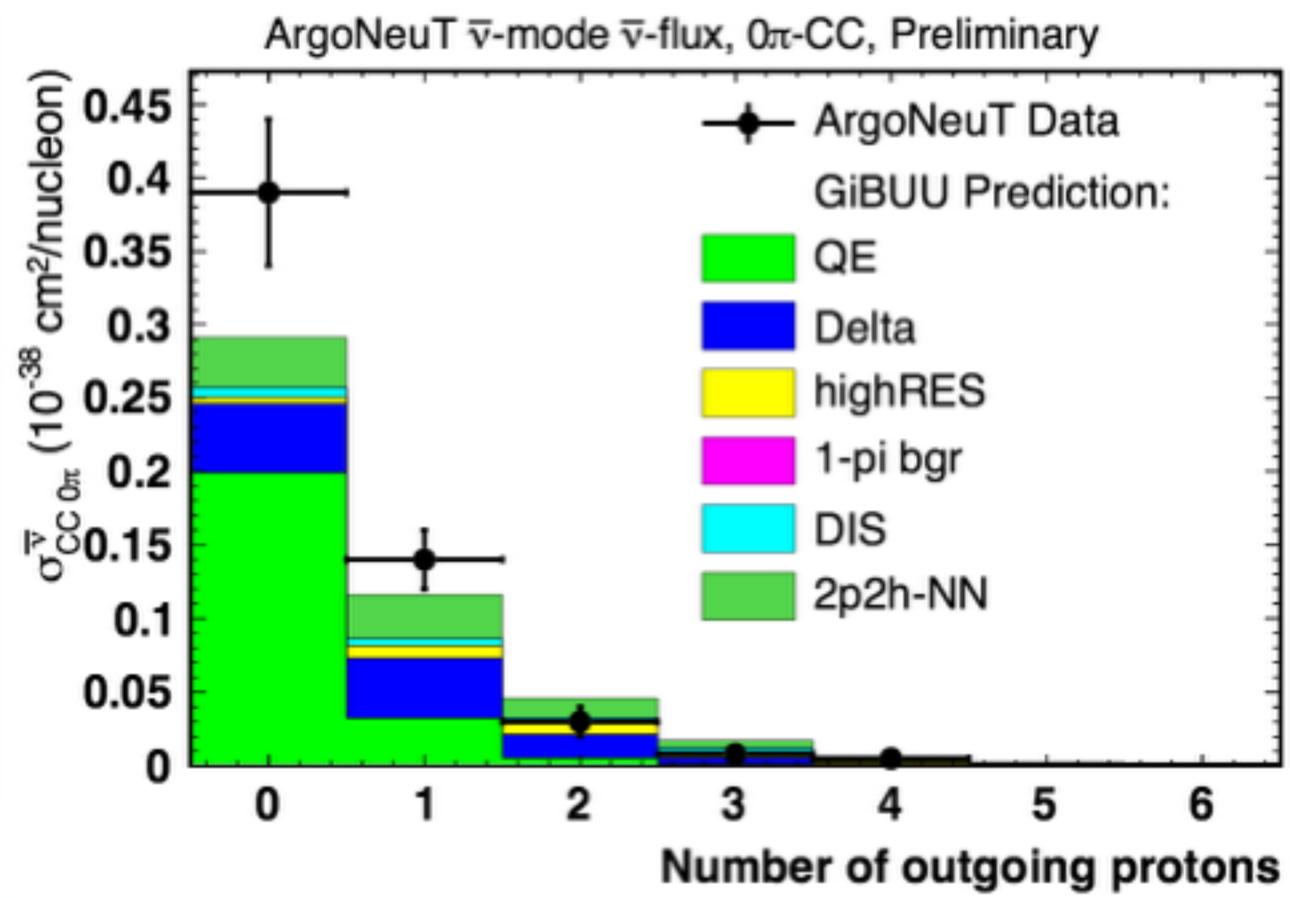
Kinetic Energy vs. track length



Calorimetry reconstruction is used by all LArTPC experiments.

Proton Multiplicity





$\sigma_{CC0\pi} = 0.71\ cm^2/nucleon$
GENIE MC

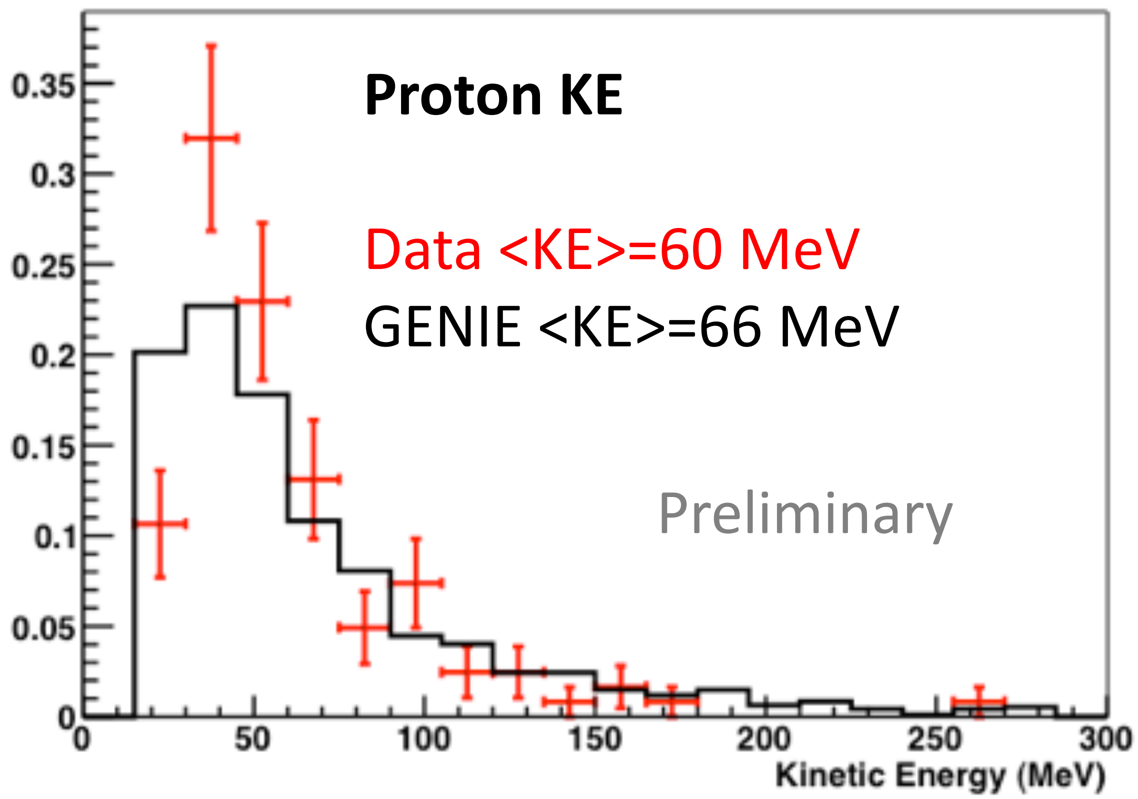
$\sigma^{\bar{\nu}}_{0\pi} = 0.48\ 10^{-38}cm^2/nucleon$
GiBUU

$\sigma^{\bar{\nu}}_{CC0\pi} = 0.58 \pm 0.03(stat.) \pm 0.06(syst.)10^{-38}cm^2/nucleon$
ArgoNeuT data

GENIE: 22% higher than data, large difference at high multiplicity
GiBBU: 17% lower than data, large difference at 0p

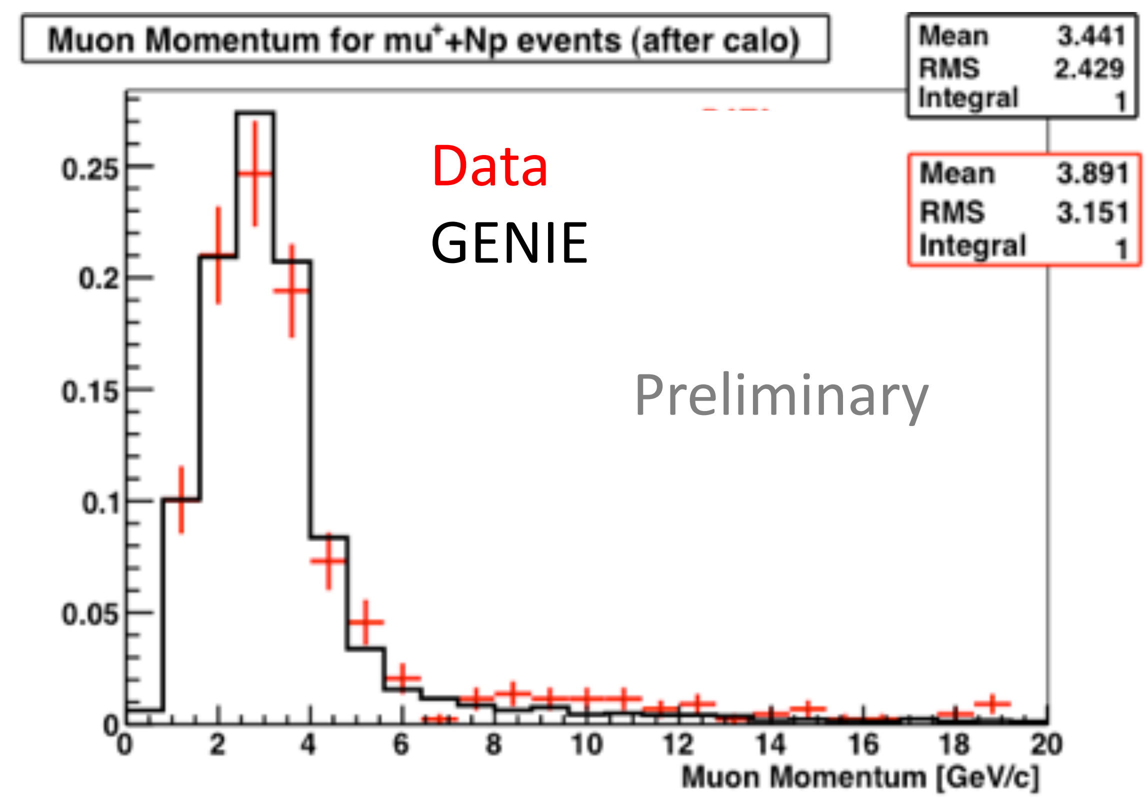
Kinematics Reconstruction (μ^++Np)

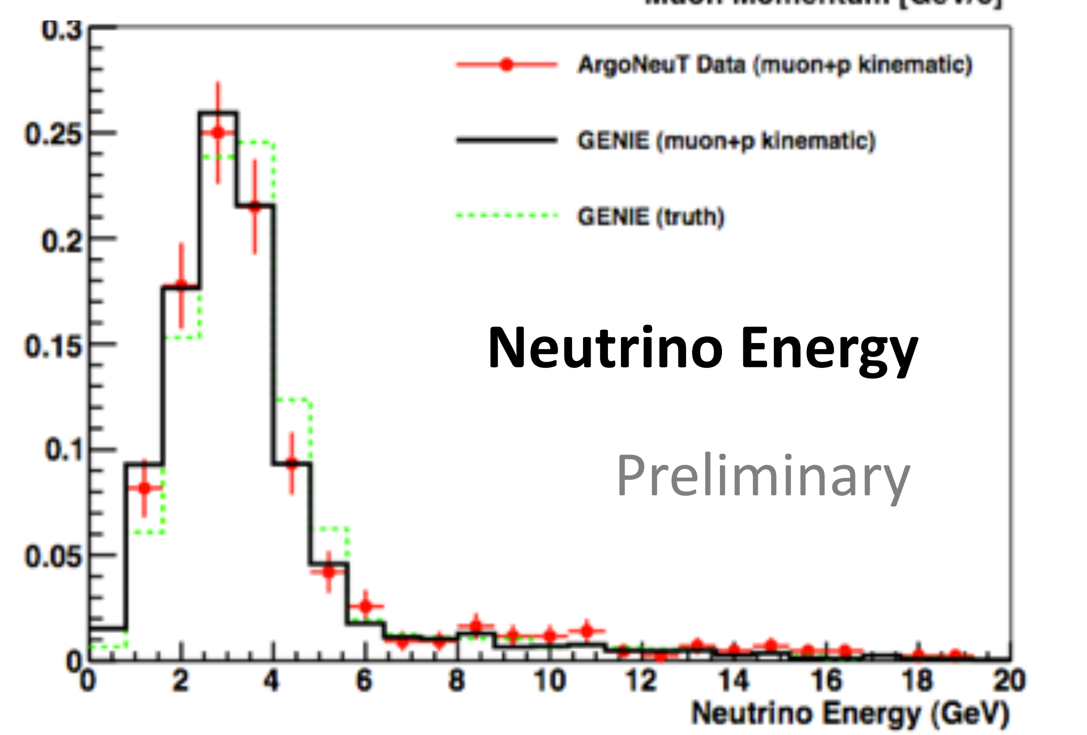
$\bar{\nu}_\mu$ – antineutrino mode run



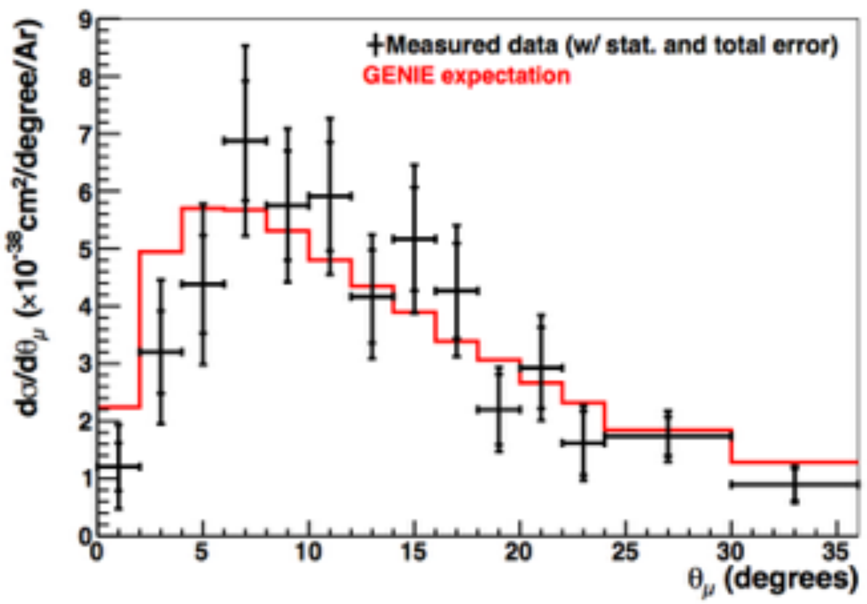
- Neutrino Energy $E_\nu = E_\mu + \Sigma T_p$
- Use all calorimetric information.

Muon Momentum

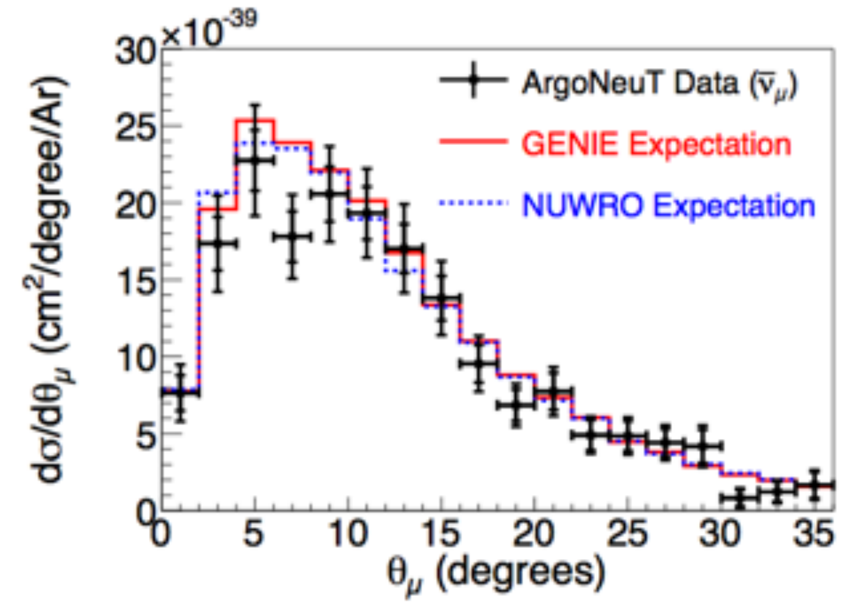




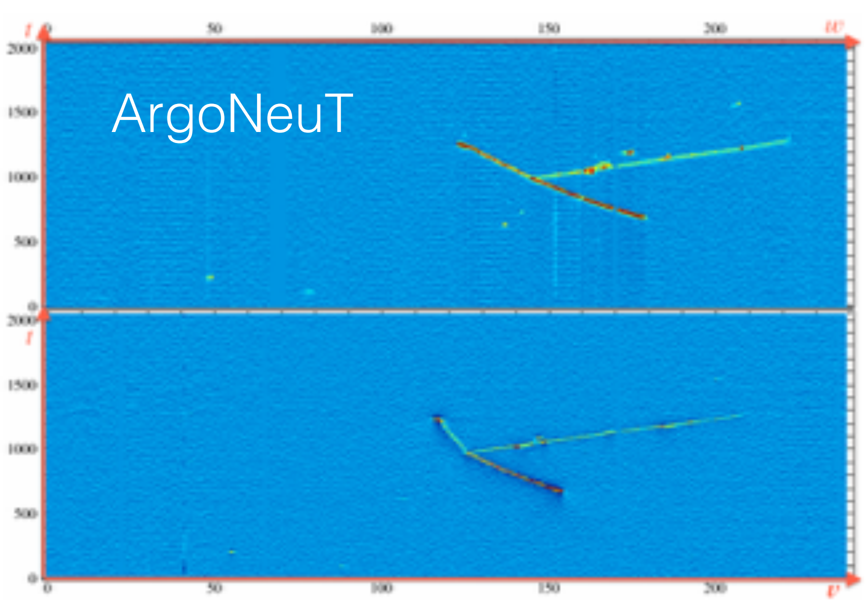
Cross section measurements



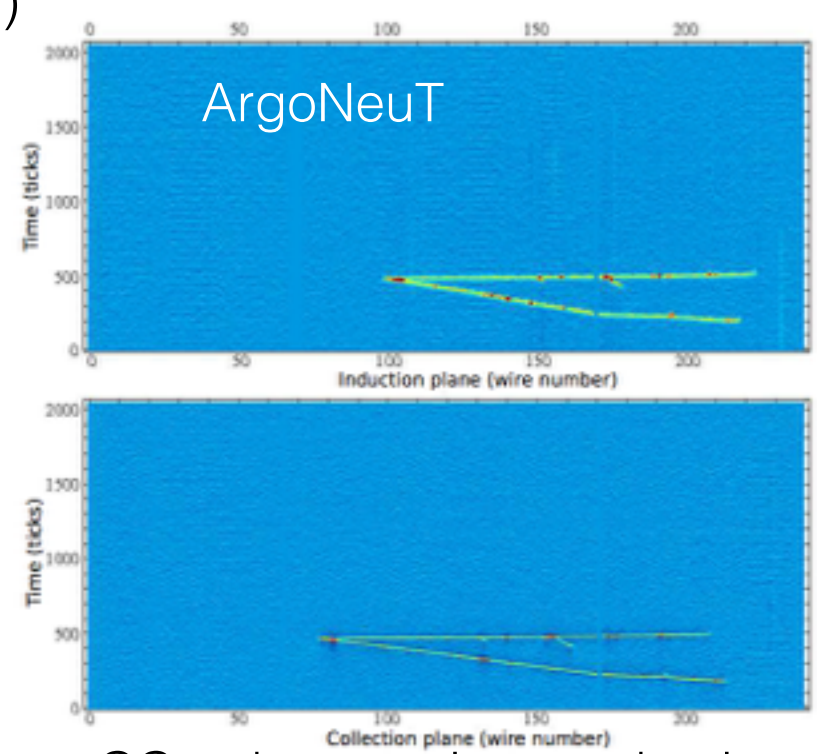
CC-inclusive, neutrino beam
1111.0103, PRL 108, 161802, (2012)



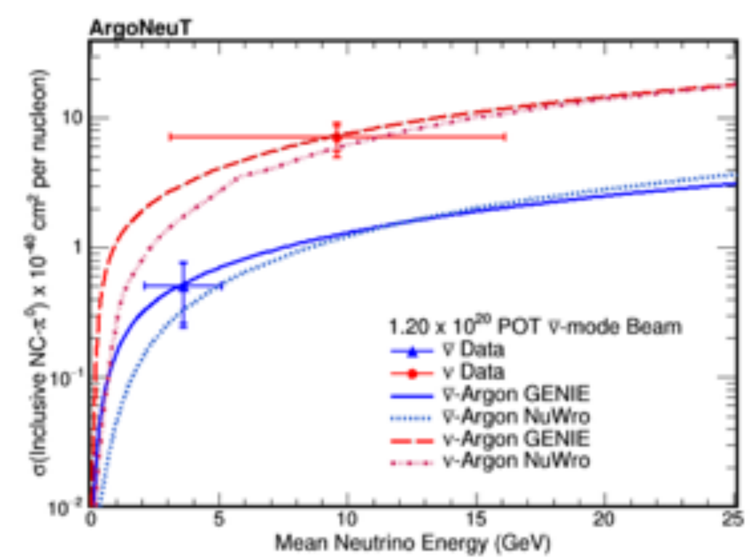
CC-inclusive, antineutrino beam
1404.4809, PRD 89, 112003 (2014)



muon+back-to-back protons
1405.4261, PRD 90, 012008 (2014)

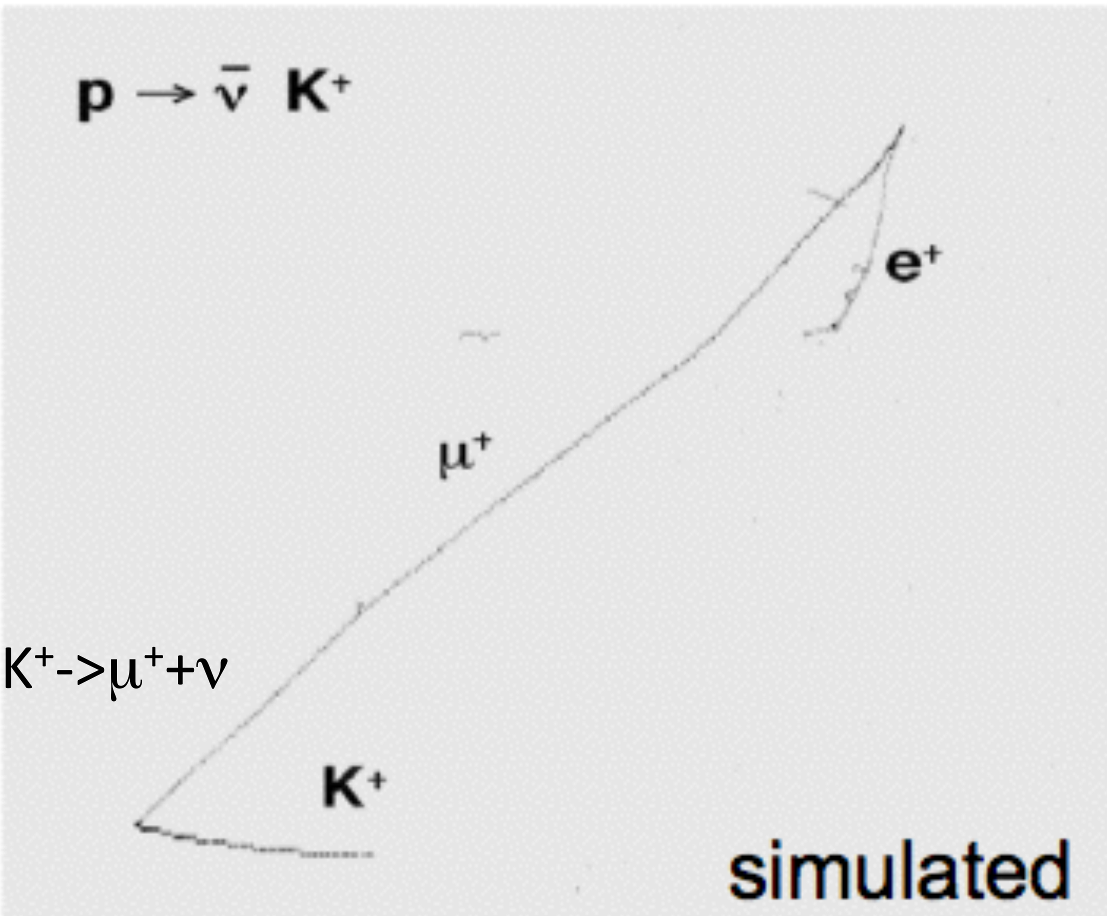


CC-coherent pion production
1408.0598, PRL113, 261801 (2014)

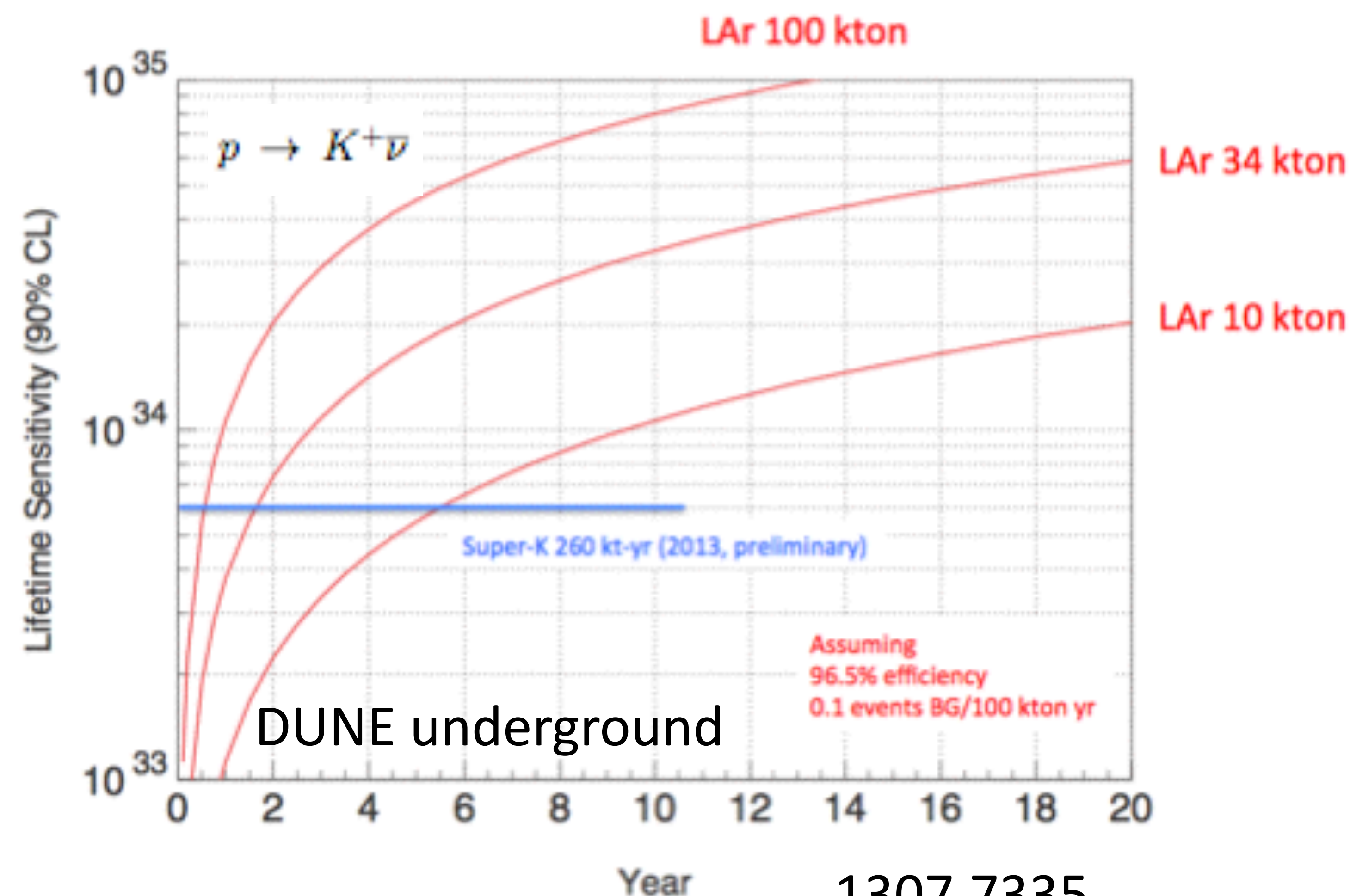


NC pi0 production
1511.00941

Proton Decay

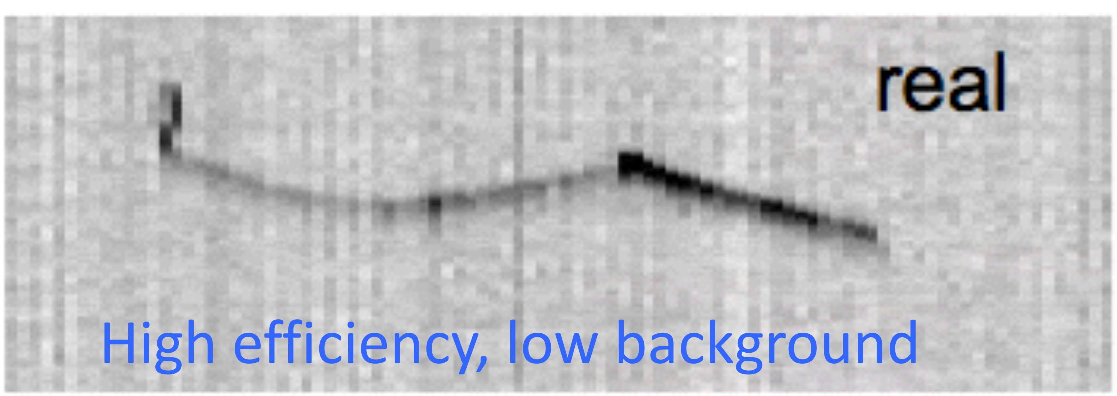


$K^+ \rightarrow \mu^+ + \nu$



DUNE underground

1307.7335



High efficiency, low background

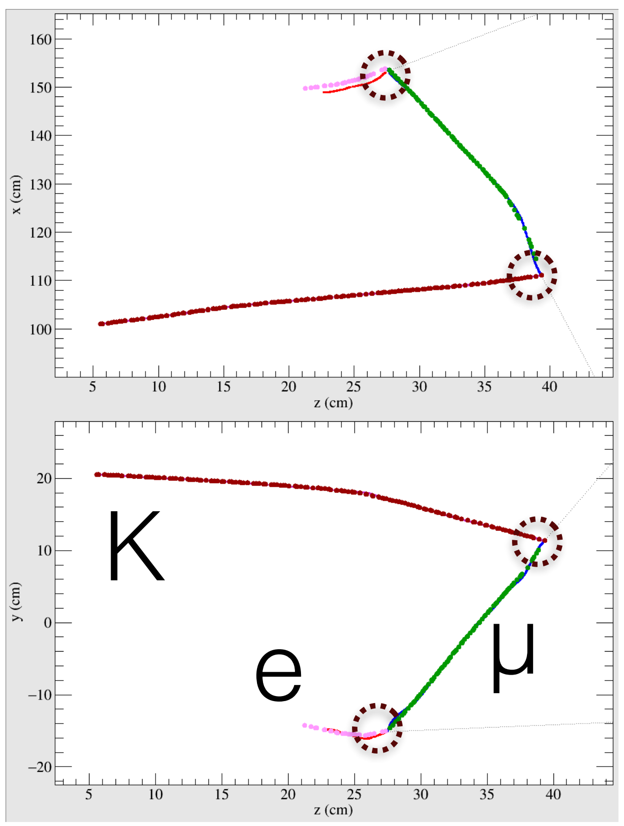
There are two favored and benchmark decay modes:
$e^+\pi^0$ (gauge mediated) and $\bar{\nu}K^+$ (SUSY D=5)
good for water — good for LAr

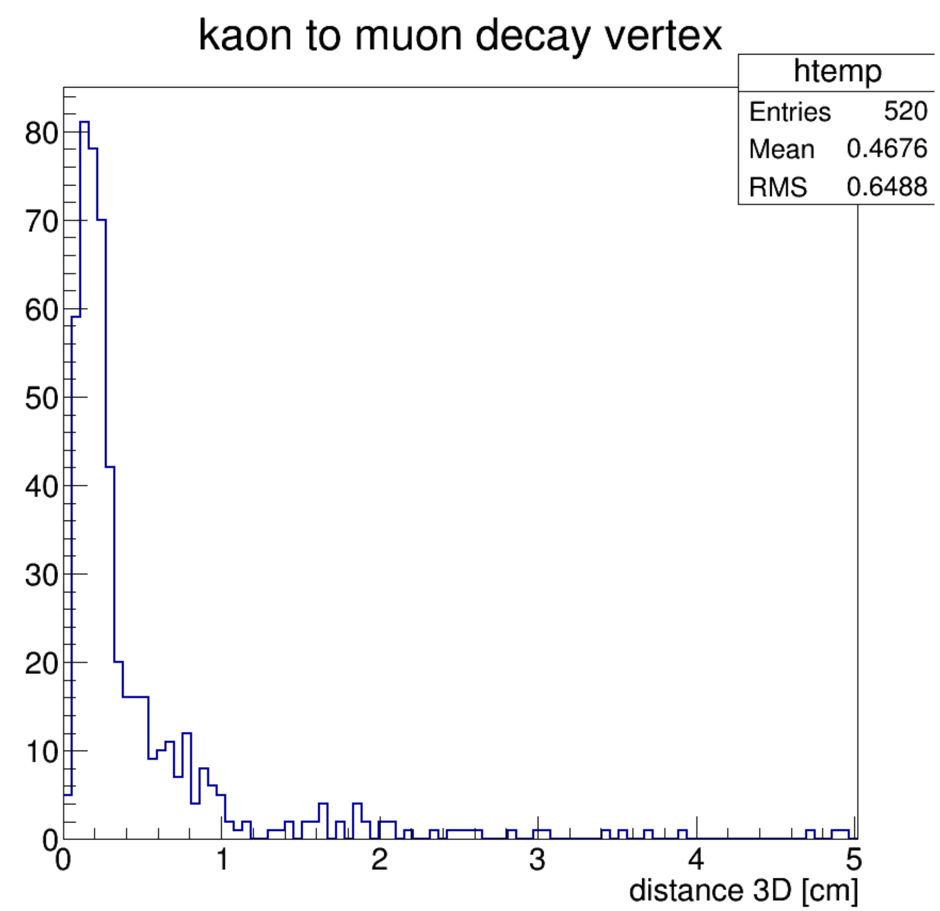
Kaon Decay Reconstruction

kaon->muon->electron

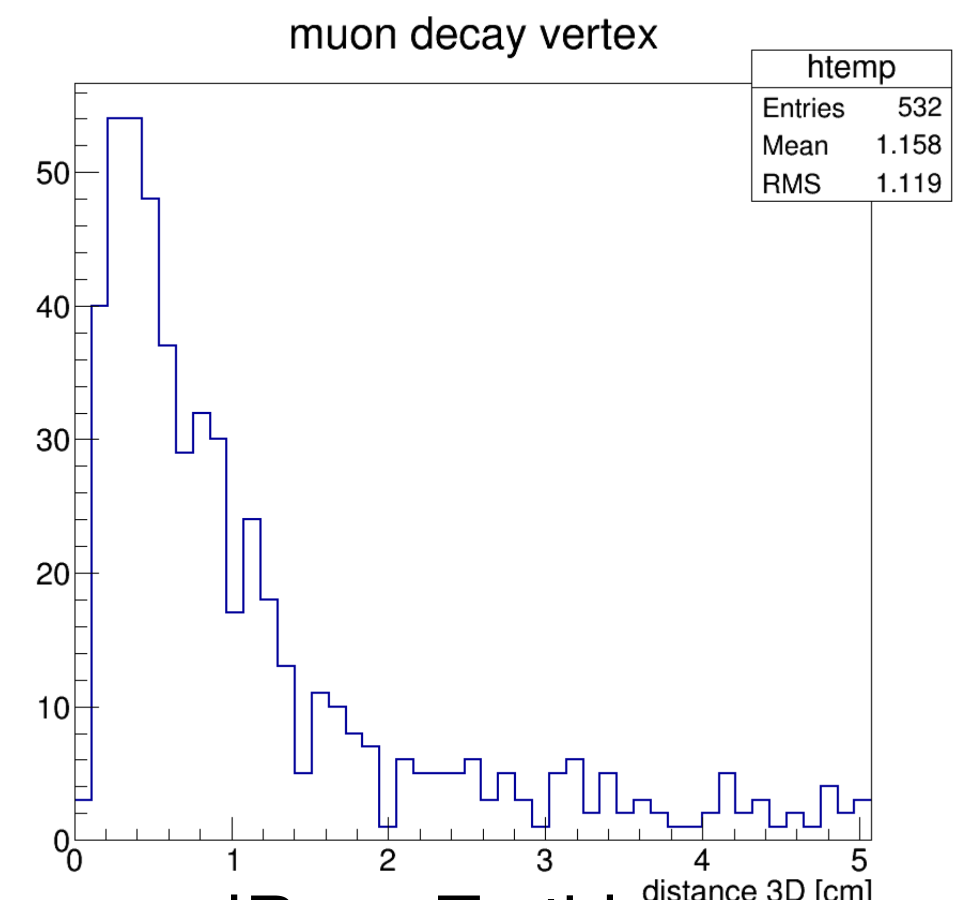
Robert Sulej

0.48 GeV/c kaon





|Reco-Truth|

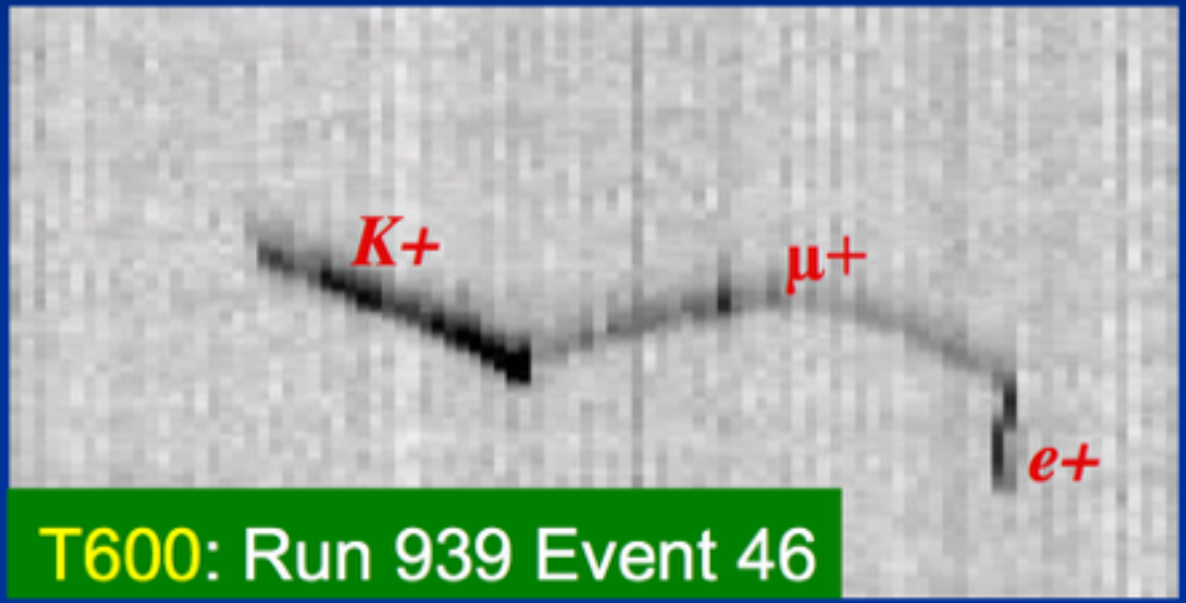


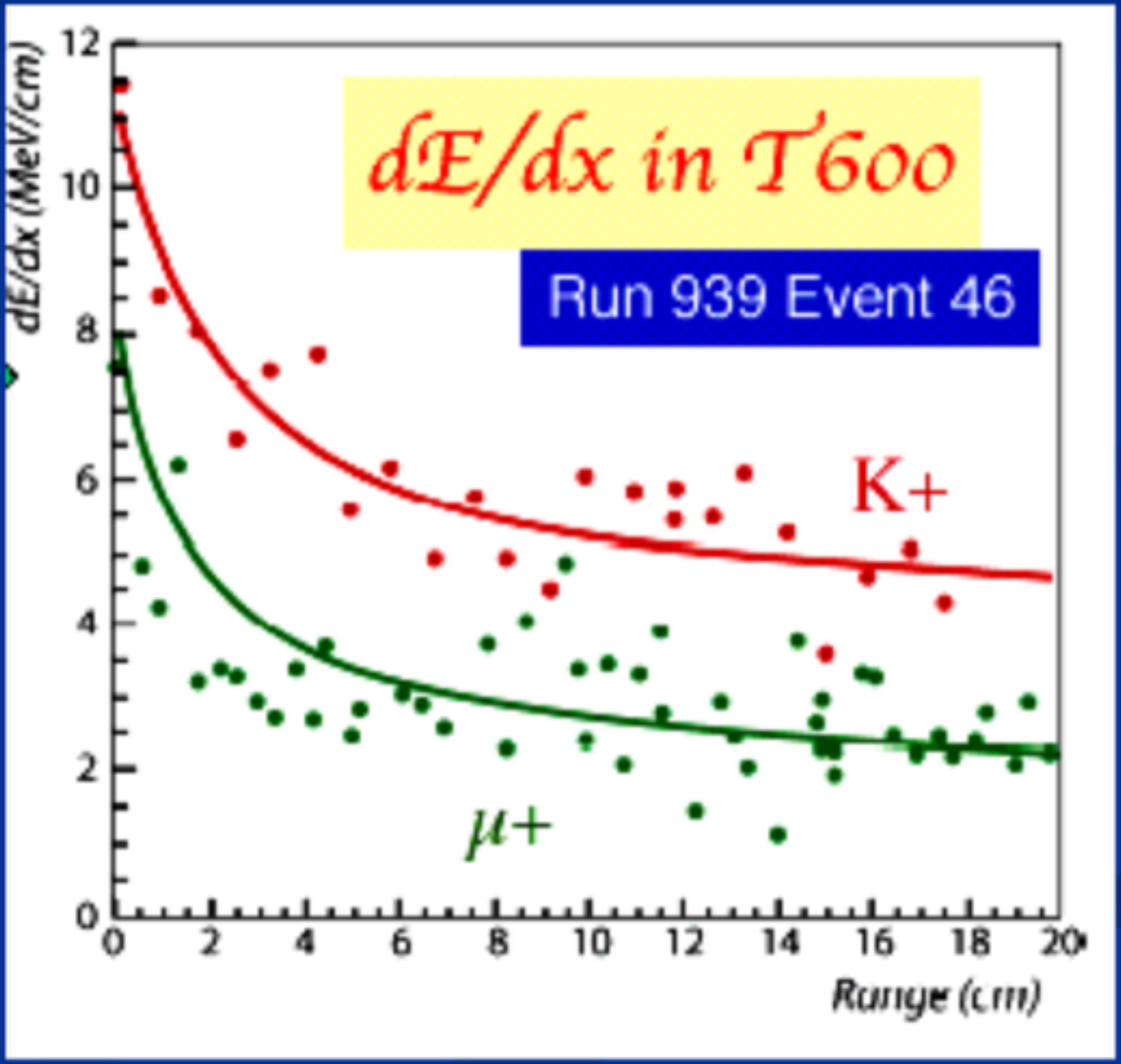
|Reco-Truth|

- Connect track ends to form vertices and reoptimize tracks.
- Both kaon decay and muon decay vertices are well reconstructed.

Kaon decay in Liquid Argon

Dorota Stefan





The energy losses per unit length of Liquid Argon follow the theoretical calculation by Bethe and Bloch

Busy Environment

- Using LArTPC in a busy environment is challenging.
  - Surface LArTPC (many cosmics in the readout window).
  - Use as a near detector (several neutrino interaction in the readout window).
  - Multiple particles in a test beam spill.
- Electron drift time is long (~ms). Cannot slice events using time information.
- Can only slice event using topological information. WireCell reconstruction is helpful in this case.

Conclusions

- The next generation of neutrino experiments have the potential to discover new physics.
- LArTPCs are ideal detectors for searching for new physics in the neutrino sector because of their high resolution.
- WireCell reconstruction has many unique features that can greatly help many physics analyses.